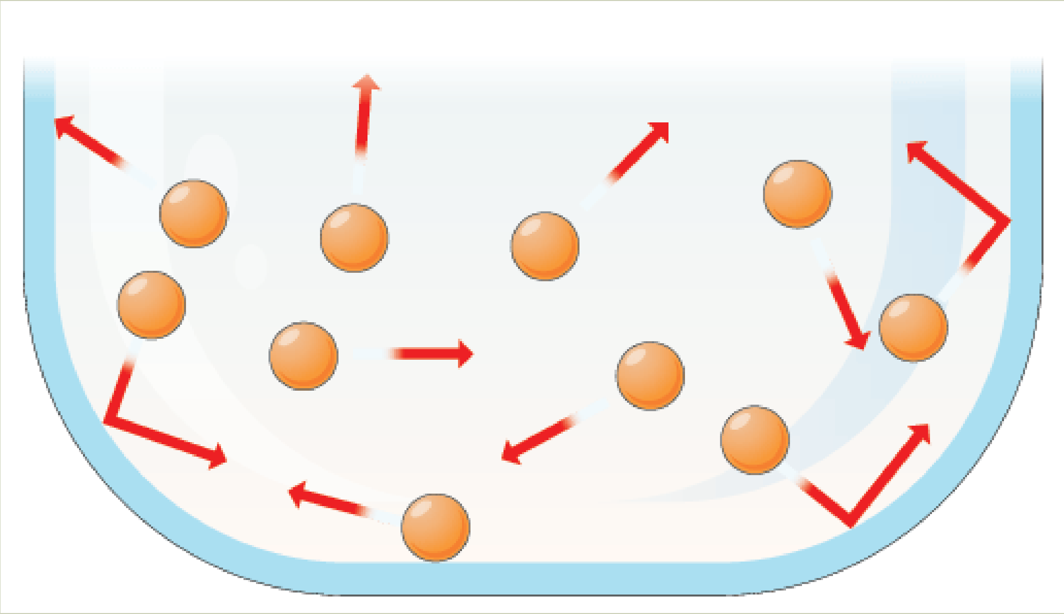
INTRODUCTION TO GASES & GAS LAWS

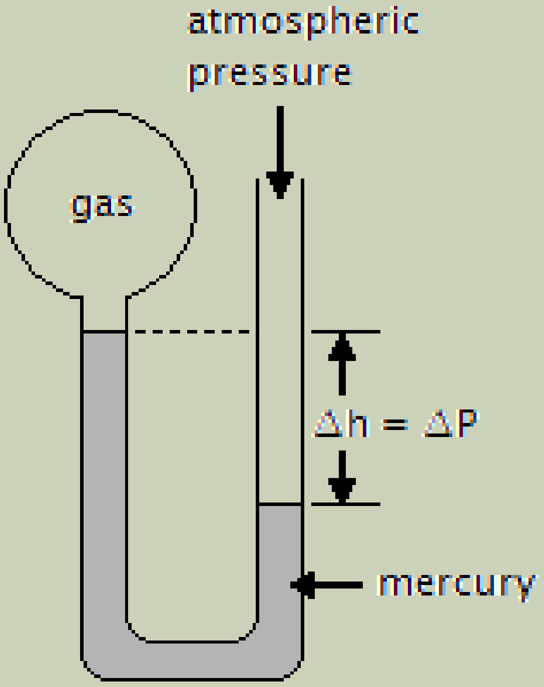
WHAT IS PRESSURE?

- Pressure—a force exerted by a substance per unit area on another substance
- For gases → exerted on the walls of their container



MEASURING PRESSURE

- Commonly use a manometer or barometer
  - Contains mercury so units in mm Hg



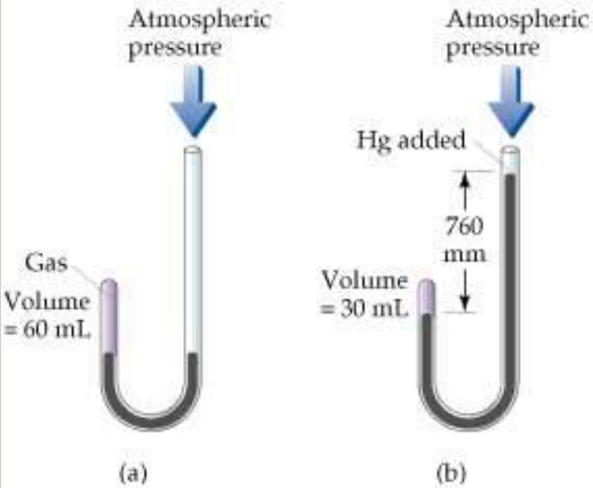
- Units of Pressure

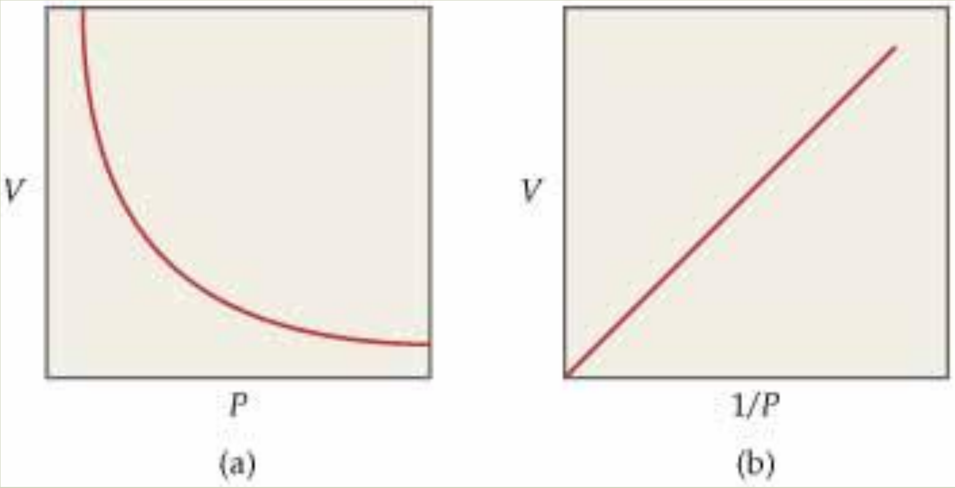
1 atm = 760 mm Hg = 760 torr = 101.325 Pa

BOYLE'S LAW

- Robert Boyle
  - Irish chemist who set up a J-shaped tube in his home
  - Studied the relationship between pressure of gas and its volume

$$PV = k \text{ or } P_1V_1 = P_2V_2$$





BOYLE'S LAW EXAMPLE

Sulfur dioxide (SO_2), a gas that plays a central role in the formation of acid rain, is found in the exhaust of automobiles and power plants. Consider a 1.53 L sample of gaseous SO_2 at a pressure of 5.6×10^3 Pa. If the pressure is changed to 1.5×10^4 Pa at a constant temperature, what will be the new volume of gas?

$P_1 = 5.6 \times 10^3$ Pa

$V_1 = 1.53$ L

$P_2 = 1.5 \times 10^4$ Pa

$V_2 = ?$

$$P_1V_1 = P_2V_2 \ \rightarrow V_2 = \frac{P_1V_1}{P_2}$$

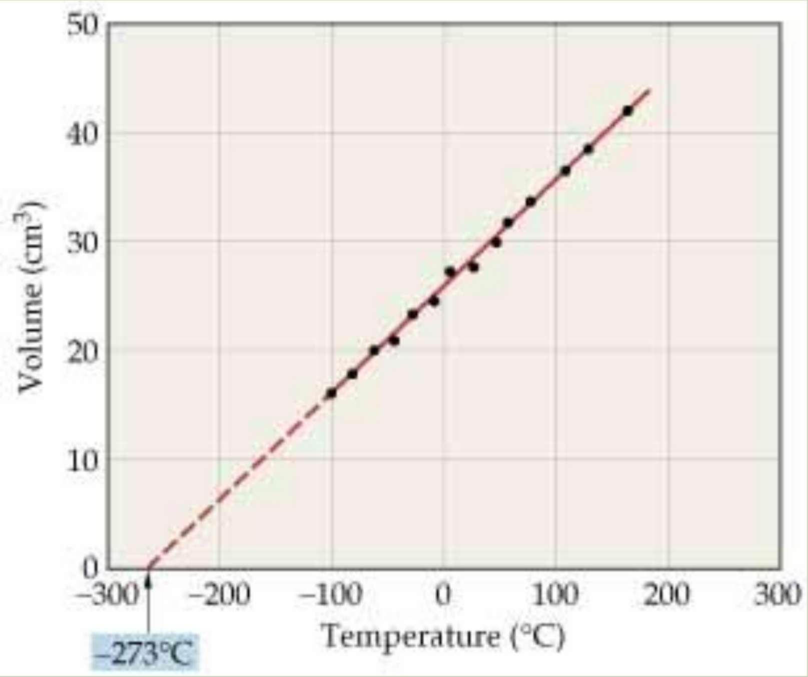
$$V_2 = \frac{(5.3x10^3\ Pa)(1.53L)}{1.5\ x\ 10^4\ Pa} = 0.57\ L$$

CHARLES' LAW

- Jacques Charles
  - French physicist who filled a balloon with hydrogen gas and made the first solo balloon flight
  - Found that volume of a gas at constant pressure increased linearly with the temperature of the gas

$$V = \frac{b}{T} \; \boldsymbol{or} \; \frac{V_1}{T_1} = \frac{V_2}{T_2}$$

- Kelvin Temperature Scale
  - K = °C + 273
  - Absolute zero
    - No energy, no movement



CHARLES' LAW EXAMPLE

A sample of gas at 15°C and 1 atm has a volume of 2.58 L. What volume will this gas occupy at 38°C and 1 atm?

T_1 = 15°C + 273 = 288 K

V_1 = 2.58 L

T_2 = 38°C + 273 = 311 K

V_2 = ?

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} \rightarrow V_2 = \frac{T_2 V_1}{T_1}$$

$$V_2 = \frac{(311\ K)(2.58\ L)}{288\ K} = 2.79\ L$$

AMONTON'S LAW

- Guillaume Amonton
  - Pressure of a gas at constant volume is proportional to the temperature
  - Discovered while developing an "air thermometer"
  - Formerly called Gay-Lussac's Law

$$\frac{P}{T} = k \;\; \boldsymbol{or} \;\; \frac{P_1}{T_1} = \frac{P_2}{T_2}$$

AMONTON'S LAW EXAMPLE

A container is designed to hold a pressure of 2.5 atm. The volume of the container is 20.0 cm^3, and it is filled with air at room temperature (20°C) and normal atmospheric pressure. Would it be safe to throw the container into a fire where temperatures of 600°C would be reached?

P_1 = 1.0 atm

T_1 = 20°C + 273 = 293 K

P_2 = ?

T_2 = 600°C + 273 = 873 K

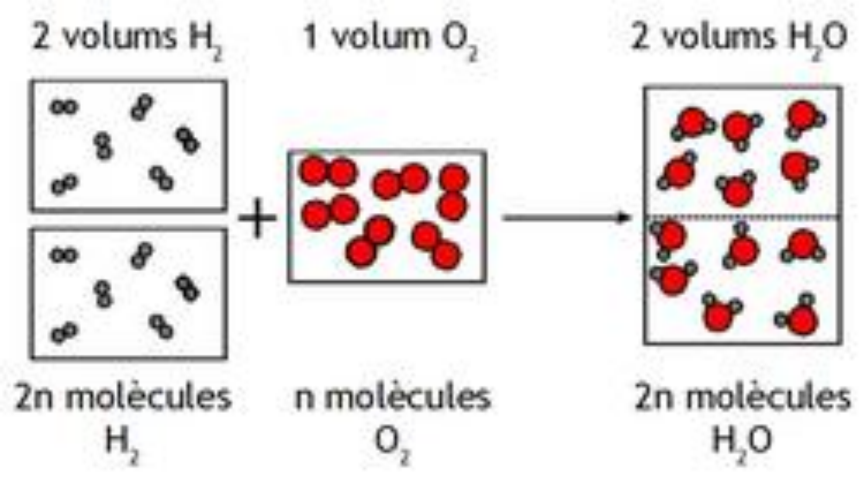
$$\frac{P_1}{T_1} = \frac{P_2}{T_2} \rightarrow P_2 = \frac{P_1 T_2}{T_1}$$

$$P_2 = \frac{(1.0\ atm)(873\ K)}{(293\ K)} = 3.0\ atm$$

AVOGADRO'S LAW

- Amadeo Avogadro
  - Found that at constant pressure and temperature, volume is directly proportional to number of moles of gas

$$V = an \ \boldsymbol{or} \ \frac{V_1}{n_1} = \frac{V_2}{n_2}$$



AVOGADRO'S LAW EXAMPLE

Suppose we have 12.2 L sample containing 0.50 mol oxygen gas at a pressure of 1 atm and a temperature of 25 °C. If all this O_2 were converted to ozone (O_3) at the same temperature and pressure, what would be the volume of the ozone?

$$3O_2\ (g) \rightarrow 2O_3(g)$$

$$0.50\ mol\ O_2\ x\ \frac{2\ mol\ O_3}{3\ mol\ O_2} = 0.33\ mol O_3$$

n_1 = 0.50 mol | n_2 = 0.33 mol

V_1 = 12.2 L | V_2 = ?

$$\frac{V_1}{n_1} = \frac{V_2}{n_2} \rightarrow V_2 = \frac{n_2 V_1}{n_1}$$

$$V_2 = \frac{(0.33\ mol)(12.2\ L)}{0.50\ mol} = 8.1\ L$$

COMBINED GAS LAW

Boyle's Law

$$P_1V_1 = P_2V_2$$

Combined Law

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

Charles' Law

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

Amonton's Law

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

IDEAL GAS LAW

- Combination of three laws:
  - Boyle's law $\rightarrow V = {}^{k}/_{P}$
  - Charles' law $\rightarrow V = bT$
  - Avogadro's law $\rightarrow V = an$

$$PV = nRT$$

- Universal gas constant (R) = 0.08206 L·atm/K·mol

- Hypothetical situation

IDEAL GAS LAW EXAMPLE

A sample of hydrogen gas has a volume of 8.56 L at a temperature of 0°C and a pressure of 1.5 atm. Calculate the moles of hydrogen molecules present in this gas sample.

P = 1.5 atm   V = 8.56 L   T = 0°C + 273 = 273 K

R = 0.08206 L·atm/K·mol

$$PV = nRT \rightarrow n = \frac{PV}{RT}$$

$$n = \frac{(1.5\ atm)(8.56\ L)}{\left(0.08206\frac{Latm}{Kmol}\right)(273K)} = 0.57\ mol$$

DALTON'S LAW OF PARTIAL PRESSURES

- Dalton's Law of Partial Pressures
  - for a mixture of gases in a container, the total pressure exerted is the sum of the pressures that each gas would exert if it were alone

$$P_{total} = P_1 + P_2 + \cdots$$

- Mole fraction
  - The ratio of the number of moles of a given component in a mixture to the total number of moles in the mixture

$$X_1 = \frac{n_1}{n_{total}}$$

DALTON'S LAW EXAMPLE

A gaseous mixture made from 6.00 g O_2 and 9.00 g CH_4 is placed in a 15.0 L vessel at 0 °C. What is the partial pressure of each gas and what is the total pressure in the vessel?

$$n_{O_2} = (6.00\ g\ O_2)\left(\frac{1\ mol\ O_2}{32.0\ g\ O_2}\right) = 0.188\ mol\ O_2$$

$$n_{CH_4} = (9.00\ g\ CH_4)\left(\frac{1\ mol\ CH_4}{16.0\ g\ CH_4}\right) = 0.563\ mol\ CH_4$$

$$P_{O_2} = \frac{n_{O_2}RT}{V} = \frac{(0.188\ mol)\left(0.0821\,\frac{Latm}{Kmol}\right)(273\ K)}{15.0L} = 0.281\ atm$$

DALTON'S LAW EXAMPLE

A gaseous mixture made from 6.00 g O_2 and 9.00 g CH_4 is placed in a 15.0 L vessel at 0 °C. What is the partial pressure of each gas and what is the total pressure in the vessel?

$$P_{CH_4} = \frac{n_{CH_4}RT}{V} = \frac{(0.563\ mol)\left(0.0821\,\frac{Latm}{Kmol}\right)(273\ K)}{15.0L}$$
$$= 0.841\ atm$$

$$P_{total} = P_{O_2} + P_{CH_4} = 0.281\ atm + 0.841\ atm = 1.122\ atm$$